Local food price analysis by linear programming: A new approach to assess the economic value of fortified food supplements

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Abstract

Linear programming can be applied to identify a nutritionally adequate diet of the lowest cost, since price and nutrient contents are linearly related to food weight. Most computer spreadsheets now include an easy-to-use solver function that is suitable for this purpose. This approach can also be used to estimate the effect of introducing a food supplement on the minimal cost required to provide a nutritionally adequate diet. It can also provide an estimate of the expenses saved by families in relation to the sums spent by the donor after the distribution of a food supplement. This method is illustrated by comparing the economic value of two food supplements, a traditional blended flour and a nutrient-dense spread (a "foodlet") in rural Chad. The limitations of this approach and the need to interpret its findings carefully in relation to field observations are discussed.

Introduction

Food fortification is often advocated on the grounds that it is an inexpensive strategy to increase the nutritional value of the diet of the poorest populations. Even if the cost of food fortification is low, its implementation requires a strong commitment from local governments, food industries, and donor agencies, who do not always perceive the benefits of this approach. In part, this is because the benefits of food fortification are not easily quantified in economic terms.

Linear programming analysis is a powerful approach for identifying a low-cost nutritionally adequate diet [1], but it has been only infrequently used for this purpose in human nutrition [2–4]. This paper also illustrates how this technique can be used to estimate the economic benefits expected from the introduction of different fortified foods using local food prices. As an example, it will compare the economic value of a classical blended food with that of a nutrient-dense spread known as a "foodlet," a highly fortified food that can be regarded as a big tablet (foodlet for food + tablet) [5], for childhood diets in Chad.

Estimation of the minimum price of a balanced ration by linear programming

Linear programming is a technique that minimizes a linear function of a set of variables while respecting multiple linear constraints on these variables. It can therefore be used to minimize the price of a diet while fulfilling constraints introduced to ensure a palatable, nutritionally adequate diet. The linear function to be minimized in this case is the cost of a balanced diet, as expressed mathematically below:

$$\text{Cost of ration} = W_1C_1 + W_2C_2 \ldots + W_nC_n$$

where C_1, C_2, C_n are the costs per unit weight of foods 1 to n.

The various constraints needed to ensure a palatable, nutritionally adequate diet include nutritional constraints on the minimum energy and nutrient content in the diet, as well as food-consumption constraints on the maximum acceptable daily portions of individual foods. These constraints should be expressed as linear constraints to facilitate the analysis, and are briefly described below.

An adequate diet can be defined as a diet fulfilling all current nutritional recommendations, with each nutrient being present in amounts equal to or superior to its recommended daily allowance (RDA). In mathematical

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terms, this can be expressed by a set of inequalities:

$$N_{11} W_1 + N_{12} W_2 \ldots + N_{1n} W_n > \text{RDA } N_1$$

$$\cdots\cdots$$

$$N_{j1} W_1 + N_{j2} W_2 \ldots + N_{jn} W_n > \text{RDA } N_j$$

where

n is the number of foods habitually consumed by the local population;

j is the number of nutrients for which an RDA is specified;

$W_1, W_2 \ldots W_n$ are the weights of foods 1 to n; and

$N_{11}, N_{12}, \ldots N_{jn}$ are the contents of nutrients 1 to j per unit of weight of food 1 to n.

All these constraints are linear constraints, because they consist of a simple sum of products. If the RDA selected for iron and zinc assumes moderate bioavailability, then an additional constraint is required on the phytate:zinc molar ratio (PZ), whereby the PZ is below 15. This constraint is not linear, because it is based on a ratio. However, it can be expressed as a linear constraint by transforming it to

$$15\, Z - P > 0$$

where Z and P are the molar zinc and phytate contents of the diet.

This equation can also be transformed into a sum of products in the following form:

$$(15Z_1 - P_1)\bullet W_1 + (15Z_2 - P_2)\bullet W_2 \ldots + (15Z_n - P_n)\bullet W_n > 0$$

where Z_n and P_n represent the molar zinc and phytate contents of food n.

If used with only nutritional constraints, linear programming can lead to unrealistic diets, since this approach will select a few low-cost, highly nutritious foods, such as beans, green leafy vegetables, dry fish, or liver, which will not be eaten in large quantities in practice. To avoid this problem, constraints on maximum daily portion sizes for each food should be introduced. Ideally these portion sizes should be defined by using food-consumption survey data collected from the population of interest or, if this is not possible, from a similar community.

Linear programming is based on a mathematical iterative approach involving multiple calculations of products and sums, which can be quickly performed by a personal computer. Calculations presented below were done with the Excel 97 (Microsoft) spreadsheet, which has a linear programming function called a "solver function" in all its recent versions. This function is found in the "tools" menu. For some versions of this program, this function is not automatically installed. However, it can be imported from the original CD of the program. It is also important to note that the options assuming that all constraints are linear and that all variables are positive should be activated before starting the analysis.

The solver function of recent spreadsheet versions also accepts nonlinear constraints in the model. Hence, constraints based on complex mathematical functions can be introduced, giving, for example, a better approximation of the mineral availability than the phytate/zinc ratio. Nonlinear programming, however, is a more complex technique and may in some cases give nonoptimal solutions, unless the analysis is repeated several times using different initial values for food variables. Therefore, only linear programming is recommended, at least in the initial stages of an analysis.

An example based on a food price survey in Chad

To illustrate the merits of linear programming for identifying low-cost diets, the minimum price of a nutritionally adequate ration for a child aged three to six years was estimated from a price survey performed in Mao, Chad. Mao is the main city of Kanem Province in a semi-desert part of northern Chad. Only a limited number of foods traditionally given to children in this area were included in the analysis.

For this analysis, local food prices were converted into prices in US$ per kilogram of the edible portion. The nutritional constraints used in the analysis were based on the preliminary World Health Organization (WHO) nutritional recommendations for children of this age group [6] for all nutrients except calcium. For calcium, the UK recommendation [7](450 mg/day) was used instead, because an optimized diet was not realizable with the use of the preliminary WHO recommendations for calcium (600 mg/day). An additional constraint was also introduced on the PZ (i.e., < 15) to warrant the assumption of moderate zinc and iron availability [8]. These constraints are presented in table 1.

To ensure that optimized diets were realistic, food constraints were also introduced that limited the daily portions of available foods (see table 2). Food-consumption data were not available for three- to six-year-old children in Chad, and therefore the 75th centiles of observed intakes of three- to six-year-old rural Malawian children were used instead, assuming that limits of intake in these two poor rural communities would be similar. These data were collected by using three-day weighed food records in the postharvest season in rural Malawi [9]. Some adjustments were also made to take into account local food availability in Mao. For example, the 75th centile for fresh fish intake in Malawi was used to define the food constraint for fresh meat intake in Chad. *Spirulina*, a green-blue alga growing spontaneously in the oasis in this part of Chad and traditionally collected and dried to prepare a nutrient-rich sauce, was also added to the food database. During the optimization process, the nutritional contents of all foods except *Spirulina* [10] were taken from the World food dietary assessment system (version 2.0) [11].

The diet obtained by cost minimization with local foods is shown in first column of table 2. Most foods present in the food database were selected, and several, such as sweet potatoes, eggs, and dried fish, were set at the maximum allowed. By definition, this diet fulfils all nutritional constraints, which means that its nutrient content is equal to or above the RDA for all nutrients. This diet should not be regarded as an ideal diet, but as the lowest-cost nutritionally adequate diet for this population where dietary quality is limited by cost.

The most difficult nutritional constraints to fulfill in this setting were energy, niacin, folate, and PZ, which were at the minimum and maximum levels for the constraints imposed (table 3). This optimized diet should be regarded as a first estimate, and it must be followed by field observations to confirm that the optimized diet is compatible with general food-consumption patterns of children in the region. Additional constraints can also be added if necessary: for example, constraints on the percentage of energy provided by different food groups to delimitate local food-consumption patterns. Conversely, some constraints may be relaxed, such as the upper limit on daily portions for highly acceptable foods. As a rule, tightening constraints will increase the estimated minimum price of a balanced ration, whereas relaxing them will lower this price.

TABLE 1. Nutritional constraints introduced in the models for estimating the minimal price of a balanced ration for three- to six-year-old children in Mao, Chad

Nutrient	Amount
Macronutrients [6]	
Energy	> 1550 kcal
Proteins	> 20 g
Minerals	
Calcium	> 450 mg [7]
Magnesium	> 76 mg [6]
Zinc	> 4.8 mg [6]
Iron	> 5 mg [6]
Phytate/zinc	< 15 mg [(8]
Vitamins [6]	
Vitamin B1	> 0.6 mg
Vitamin B2	> 0.6 mg
Vitamin B6	> 0.6 mg
Niacin	> 8 mg
Folate	> 200 µg
Vitamin B12	> 1.2 µg
Vitamin C	> 30 mg
Vitamin A	> 450 µg RE

TABLE 2. Food consumption constraints imposed during optimization, and daily portions of foods selected for an optimized (low-cost, nutritionally adequate) diet for a three- to six-year-old child, with and without introduction of traditional blended flour and highly nutrient-dense spread in the linear programming model

Food	Maximum amount of food allowed during diet optimization (g)	Amount of food selected (g)[a]		
		Only local foods	Flour added[b]	Spread added[c]
Spirulina alga	5	**5**	0	0
Groundnuts	45	0	0	0
Banana	75	**75**	0	0
Maize flour	255	0	53	**255**
Millet flour	175	71	23	0
Dried okra	65	33	0	0
Oil	17	**17**	**17**	**17**
Cowpeas	60	16	6	3
Eggs	40	**40**	0	0
Onions	4	**4**	0	0?
Sweet potatoes	165	**165**	156	6
Dried fish	25	**25**	**25**	12
Rice	110	**110**	110	39
Mutton	80	**80**	0	36
Nutrient-dense spread	40	NA	NA	26
Blended flour	255	NA	120	NA
Cost (US$)		0.704	0.329	0.286

a. Foods set at their maximum level by linear programming are in boldface type. Amounts are given for foods as bought from the market, before preparation. NA, not allowed.

b. Estimated cost: US$1/kg.

c. Estimated cost: US$3/kg.

This example has been presented to demonstrate how linear programming can be used to delineate the minimal cost required to provide a nutritionally adequate diet for a population of three- to six-year-old children in this part of rural Chad. Such information is useful for nutrition education purposes and for evaluating economic factors in relation to dietary adequacy.

Comparison of the economic impact of two possible food aid programs in Chad

In some communities, an affordable, nutritionally adequate diet based on local foods may be difficult to achieve without the introduction of a low-cost fortified-food supplement. In these circumstances, linear programming analysis can be used to evaluate the effect of alternative food supplements on the price of a ration. To illustrate this application of linear programming, we have compared the economic value of two food supplements, a traditional blended flour and a highly nutrient-dense spread, defined as a "foodlet" [12]. Their nutritional values are shown in table 4. For nutrient-dense spread, the fortification levels chosen were those previously field-tested in Algeria [13]. High fortification levels are made possible in this spread by the attractive taste of peanut, which can easily hide high levels of unpalatable vitamins and minerals. The flour was a blend of maize and cowpea flours with sugar, fortified with a standard mineral and vitamin mix [14]. This formula of this blend is similar to that of the blended flour produced and distributed in food-supplementation programs in Chad in recent years.

TABLE 3. Nutritional content of diets for a three- to six-year-old child selected by linear programming analysis[a]

Nutrient	Only local foods	Flour added	Spread added
Macronutrients			
Energy (kcal)	**1,550**	**1,550**	**1,550**
Protein (g)	60	49	40
Minerals (mg)			
Calcium	546	617	**450**
Magnesium	179	215	388
Zinc	7	11	20
Iron	13	20	16
Phytate/zinc < 15 mg	**15**	**15**	14
Vitamins			
Vitamin B1 (mg)	0.63	0.92	1.88
Vitamin B2 (mg)	0.81	1.01	1.53
Vitamin B6 (mg)	1.3	1.2	1.7
Niacin (mg)	8	14	23
Folate (μg)	**200**	293	**200**
Vitamin B12 (μg)	1.3	1.2	1.2
Vitamin C (mg)	39	64	**30**
Vitamin A (μg RE)	1,850	2,130	526

a. Nutrients set at their allowed limit by the program are in bold type.

To estimate the maximum amount of blended flour a child of this age can reasonably eat per day, the 75th centile of intake for maize flour in Malawi was chosen [9]. For nutrient-dense spread, it was limited to 40 g, which was the average intake observed in the supplementation study in Algeria on children aged three to five years.

In this example, it was assumed that blended flour and nutrient-dense spread could be produced in N'Djamena, the capital city of Chad, and transported to Mao at a cost of US$1 and US$3 per kilogram, respectively. These figures—although realistic—are used only to illustrate the use of linear programming and should not be taken literally. The production costs for nutrient-dense spread were estimated from the price of locally available ingredients and the cost of adding a mineral and vitamin mix.

Table 2 shows the optimized ration and minimal costs obtained when blended flour and nutrient-dense spread were added to the list of foods available for selection in the ration, using the same constraints as those previously described (see tables 1 and 2). As outlined above, these rations must be interpreted carefully and ideally should be field-tested for their acceptability and, if necessary, reanalyzed using additional constraints.

To illustrate the use of linear programming for defining the economic impact of fortified supplements, we will assume that the proposed diets (table 2) were acceptable and palatable. This analysis showed that the inclusion of either blended flour or nutrient-dense spread in the model decreased the estimated minimum

TABLE 4. Nutritional composition of traditional blended flour and highly nutrient-dense spread (per 100 g)

Nutrient	Flour	Spread
Energy (kcal)	330	630
Protein (g)	12	10
Minerals (mg)		
Calcium	126	1000
Magnesium	58	156
Iron	12	42
Zinc	6	41
Phytates	544	289
Vitamins		
Vitamin A (μg RE)	400	2000
Vitamin C (mg)	30	125
Vitamin B1 (mg)	0.4	3.5
Vitamin B2 (mg)	0.5	4
Vitamin B6 (mg)	0.2	3.5
Vitamin B12 (μg)	1	3.5
Folic acid (μg)	200	500
Niacin (mg)	6.8	50

price of a balanced ration (table 2), using quantities less than the maximum limit specified in the program. Assuming that these foods are distributed freely (food aid), the resultant savings for a nutritionally adequate diet per child per family will be equal to the difference between the total cost of the diet without and with the supplement (both costs shown in table 2) plus the price of the supplement itself. In this example, this saving (D in table 5) is slightly higher for blended flour than for nutrient-dense spread. In contrast, the ratio between the amount saved by the families and the amount spent by the donors (R in table 5) is higher for nutrient-dense spread than blended flour, because of the higher cost of blended flour (B in table 5).

The latter gives a better comparative estimate of the economic value of the alternative food supplements evaluated (i.e., each US$1 spent by the donor on nutrient-dense spread saved US$7.07 for the families, as compared with US$4.15 for blended flour). In other words, in this example, the foodlet would be more cost-effective than the traditional blended food. These results were not easily predictable when the costs were compared in isolation (i.e., the prices per kilogram and per quantity of energy), a result emphasizing the merits of this type of analysis.

This analysis will also show when a proposed program has a ratio of amount saved to amount spent less than 1, which means that the money saved by the families will be below the amount spent by the donor. This is likely to be the case for unfortified blended flour prepared from locally available foods: these foods are more expensive than the sum of the basic ingredients used in their composition and have no superior nutritional value compared with the meal a mother would prepare at home with the same ingredients.

Limitations of the presented approach and possible future applications

Linear programming is a very powerful tool for analyzing the cost of a nutritionally adequate ration prepared from different locally available foods. Only the general principles and selected applications of the approach have been presented here. It is noteworthy that this method could be further refined by taking into account costs not included in this example, such as the cost of targeting food distribution, of administrative overheads, or of training food aid staff. It could also take into account foods grown by the family by giving them an economic value.

The sensitivity of linear programming to selected constraints, however, is its major weakness. Clearly, this approach should not be used in isolation, and the validity of its conclusions should be field-tested. The chosen set of nutritional constraints should be based on internationally accepted nutritional recommendations, such as those published by international organizations. Ideally, the food-consumption constraints used in the model should be derived from food-consumption data collected in the community of interest. In their absence, constraints based upon survey data collected in a comparable environment, as presented in this example, may be a useful starting point for the analysis. Building up an international database of food-consumption constraints for different age groups, especially for nutrient-dense foods, would facilitate the application of this method. The validity of these constraints could then be confirmed and if necessary adjusted on the basis of a series of simple observations in the community itself.

This method has wide applications for different types of nutrition-intervention programs, including supplementation, fortification, and agriculture programs. Despite its limitations, it clearly provides useful information for evaluating the economic benefits of different intervention programs for the poor.

Acknowledgments

The authors wish to thank Mr Radandi Lacsala, Centre de Nutrition et de Technologie Alimentaire, N’Djamena, République du Tchad, for his help during the price survey in Mao (Kanem).

TABLE 5. Estimation of the economic impact and efficacy of blended flour and highly nutrient-dense spread

Food	Minimum cost of ration for child with fortified supplement (A) (from table 2) (US$)	Cost of supplement (B) (price per kilogram amount in table 2)(US$)	Estimated cost for family of ration for child when food supplement is given C = (A–B)(US$)	Estimated saving for family to feed child balanced diet when supplement is given D = (MEP[a] – C)(US$)	Ratio of amount saved by family to amount spent by donor (R = D/B)
Flour	0.33	0.12	0.21	0.50	4.2
Spread	0.29	0.07	0.22	0.49	7.1

a. MEP, Minimum estimated price for a nutritionally adequate diet for a three- to six-year-old child from local foods: US$0.70.

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